Performance of Photovoltaic Modules in Calabar, Southern Nigeria

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ABSTRACT

The effect of intensity of solar radiation, relative humidity and ambient temperature on the efficiency of monocrystalline and polycrystalline photovoltaic modules in the generation of electricity in Calabar, southern Nigeria has been investigated. The datacollated for the related parameters was graphically analysed. The results indicate that the efficiency of both solar module types increase positively with increase in solar radiation and ambient temperature but decrease with rising relative humidity. Daily average efficiency of monocrystalline and polycrystalline modules was found to be 10% and 12% respectively with average daily output power of 34W and 40W respectively for the 130W rated solar module used in the investigation. It has been further found that the polycrystalline modules show higher efficiency in this clime than the monocrystalline types. Inherent loss mechanisms such as heat loss, spectral loss, and emission loss have not been accounted for.

Keywords:*array, efficiency, monocrystalline, output power, photovoltaic, Polycrystalline, solar electricity, solar modules.*

1. INTRODUCTION

The growing worldwide demand for more energy, its increasing cost as well as the rapid depletion of fossil based non-renewable energy reserves make renewable sources of energy an inevitable alternative for the positive survival of mankind. It is estimated by Hohlein et at., (2003) that by 2030 man will have to depend more on renewable sources of energy.

Photovoltaic (PV) systems have been found to offer one significant source of renewable energy. Thishas to do with direct conversion of solar energy to useable electricity. According to Babatunde et al., (2012), Nigeria (lying in the tropics) receives abundant sunshine, where about 1500PJ (about 258 million barrels of oil equivalent) could be available from solar energy, if solar appliances like the PV modules with only 5% conversion efficiency were used over only one percent of the total land area of the country for about six months a year.

The PV module, also known as solar module and solar panel, consists of several solar cells connected in various series and parallel arrays, rated in watt (W) based on the maximum power the modules can produce under ideal solar radiation and temperature conditions. The rated output of the PV modules is used to determine the number of modules or the array required to meet one's electricity needs.

In practice, the PV arrays are mounted at some fixed angle of 5 to 10 degrees facing south in Nigeria or they are mounted on a tracking device that follows the direction of the sun.

If properly maintained, PV arrays can attain a life span of up to 50 years as they can withstand extreme weather conditions.

2. THEORETICAL BACKGROUND

The operation of photovoltaics for generation of electricity is based on the inner photoelectric effect, also referred to as the photovoltaic effect. This effect realises the generation of potential difference at the junction of the two different materials in response to electromagnetic radiation, which solar radiation is. Electrons are emitted from a material that has absorbed solar radiation with a frequency above a certain material dependent threshold frequency.

Conversion efficiency of a solar cell energy is given as the percentage of the power converted from sunlight (solar radiation) to electrical energy under standard test conditions (STC) which are based on some theoretical limit calculations. These assume the irradiance of $1KWm^{-2}$, temperature of 25^oc and 1.5g solar air mass. The best modern production silicon cell efficiency of 24% at the cell level and 20% at the module level was reported by SunPower in March 2012.

Efficiency which is a measure of the performance of the PV system is given mathematically as

$$\text{Efficiency} = \frac{\text{Output Power of solar panel (W)} \times 100\%}{\text{solar panel area } (m^2) \times \text{Solar Radiation } (Wm^{-2})}$$

This shows direct proportionality between efficiency performance and output power of the PV module.

3. METHODOLOGY

The PV modules employed in this study were the commercial photovoltaic Yingli solar YS130 monocrystalline and polycrystalline models, rated at 130W each. The open circuit voltage $V_{oc}$and short circuit current I_{sc} from both types of solar modules were measured simultaneously by a Hyelec auto range digital multimeter model MS8236. A direct display KT908 digital Thermo-Hydrometer provided values for ambient temperature and relative humidity at the location simultaneously, while the TES 1333 model solar power meter measured solar radiation. This instantaneous data collection with the aid of the devices listed above was done at 15 minutes intervals daily (06.00 - 18.00 LT) for 7 days in the month of February.

4. RESULTS

The data collected for the related parameters is graphically represented in figures 1 to 12. Figures 1 to 6 show the variation of efficiency of the PV system in Calabar with solar radiation, ambient temperature and relative humidity for both monocrystalline and polycrystalline modules. Lines of best fit, as obtained from some simple software have been employed for a clearer picture of the relationships. The related regression equations are indicated on the respective graphs.

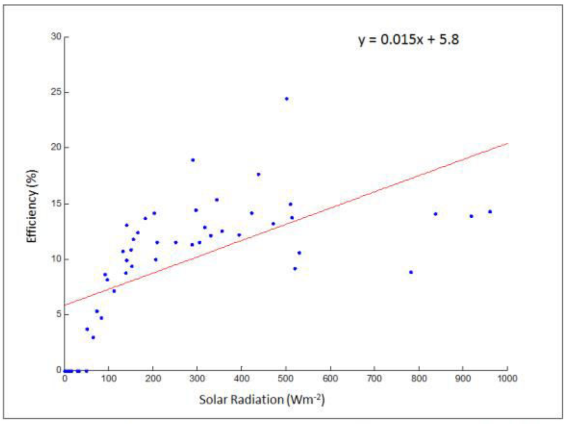

Figure 1 Graph of Monocrystalline Efficiency against Solar Radiation in Calabar

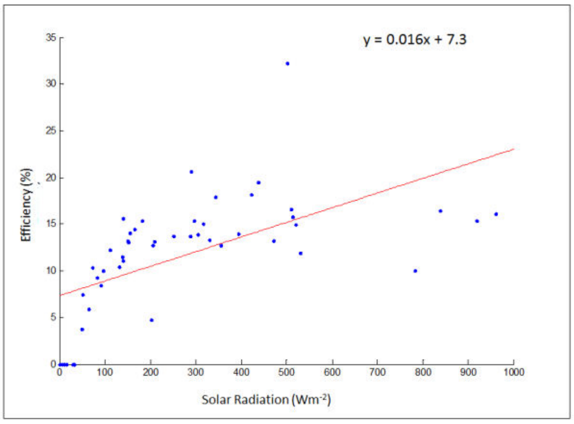

Figure 2 Graph of Polycrystalline Efficiency against Solar Radiation in Calabar

Figures 7 to 9 show the corresponding lines of best-fit for graphs of module efficiency against solar radiation, ambient temperature and relative humidityfor the two types of modules.

Figures 10 to 12 present the output power (W) plotted against the key parameters of solar radiation, ambient temperature and relative humidity for the two types of PV modules.

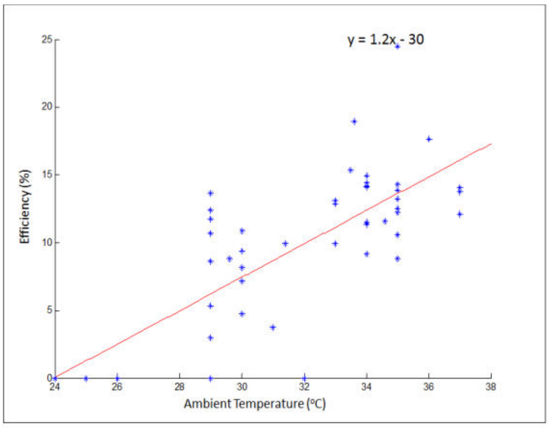

Figure 3 Graph of Monocrystalline Efficiency against Ambient Temperature in Calabar

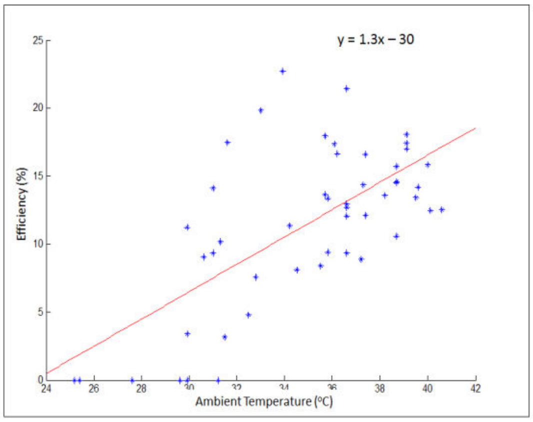

Figure 4 Graph of Polycrystalline Efficiency against Ambient Temperature in Calabar

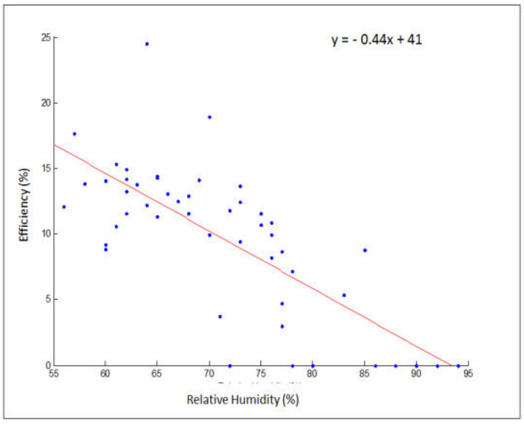

Figure 5 Graph of Monocrystalline Efficiency against Relative Humidity in Calabar

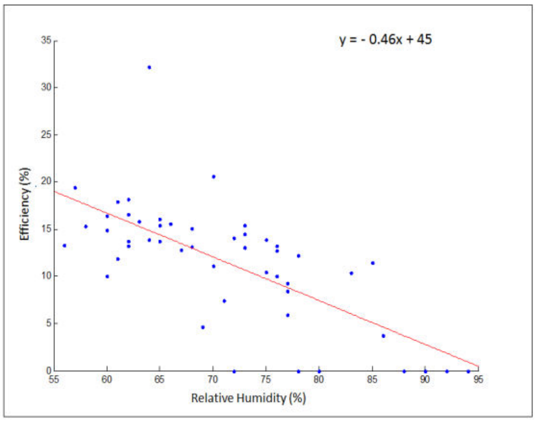

Figure 6 Graph of Polycrystalline Efficiency against Relative Humidity in Calabar

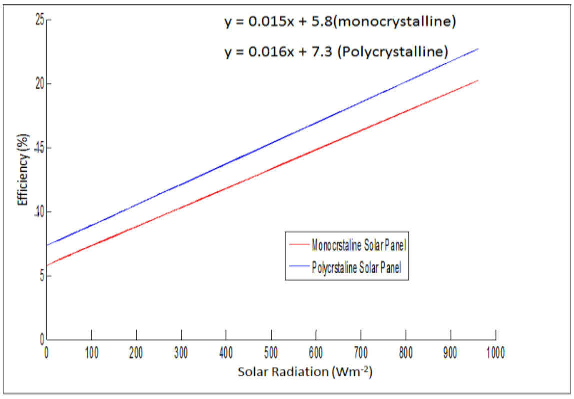

Figure 7 Graph of Efficiency against Solar Radiation in Calabar

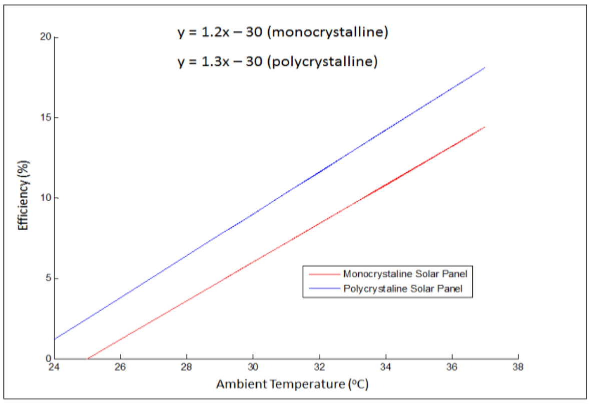

Figure 8 Graph of Efficiency against Ambient Temperature in Calabar

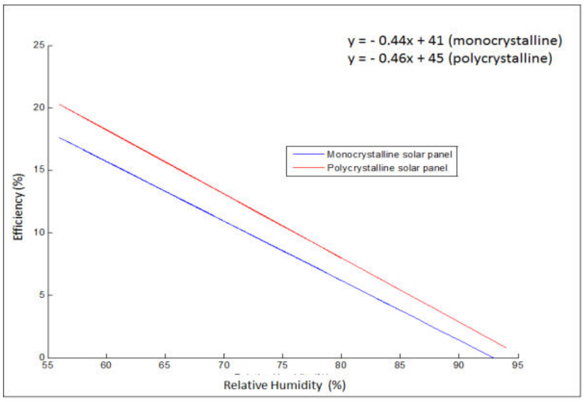

Figure 9 Graph of Efficiency against Relative Humidity in Calabar

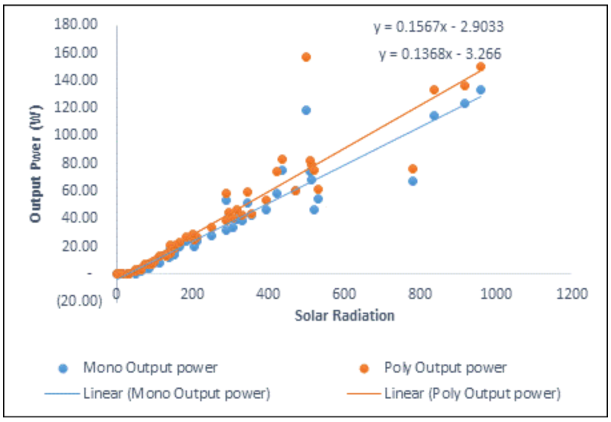

Figure 10 Graph of Output Power against Solar Radiation in Calabar

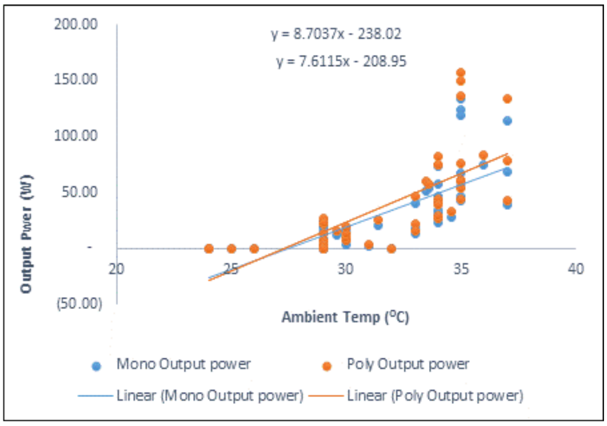

Figure 11 Graph of Output Power against Ambient Temperature in Calabar

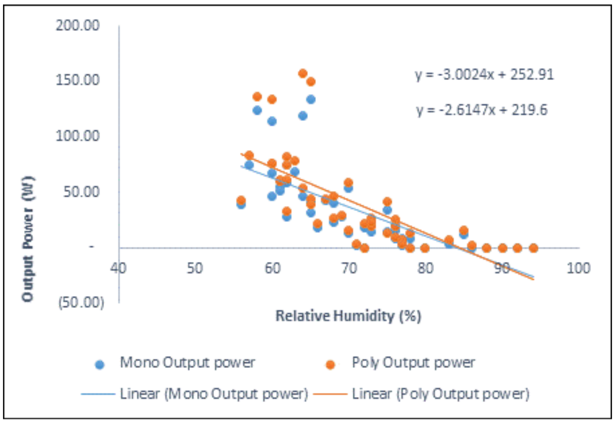

Figure 12 Graph of Output Power against Relative Humidity in Calabar

5. DISCUSSIONS

The average daily output power of 34W and 40W obtained in this study for the monocrystalline and polycrystalline solar modules respectively vis-a-viz their 130W rating can be explained in that the actual output from the solar modules as installed at various operational locations generally differ substantially from the rated output on account of local meteorological conditions (Siddiqui and Bajpai, 2012).

It is to be expected that there is a direct proportional increase in PV module efficiency with increase in solar radiation intensity as well as with increase in the ambient temperature, as can be seen in the positive slopes in Figs 7 and 8. This holds for both PV module types and agrees with similar reports by Omubo- Pepple et al. (2009). It is further observed that the slopes of polycrystalline PV types are greater than those of the monocrystalline PV type.

In contrast, Fig 9 shows increase in module efficiency with decrease in relative humidity. This is to be expected because relative humidity reduces the amount of solar radiation incident on the solar modules. It is noticed that the efficiency gets to zero at relative humidity of about 94% for the monocrystalline and between 95% and 100% for the polycrystalline PV type.

The relationship between output power from the PV modules and the parameters of solar radiation, ambient temperature and relative humidity in Figs 10 -12 show similar proportionality.

Contrary to findings and reports by Abdelkader et al. (2010), Uguoke and Okeke (2012), which posited that monocrystalline solar modules are more efficient than polycrystalline modules, our results have shown that the average daily efficiency of polycrystalline PV modules are rather higher.

By extrapolation to lower values of the independent variables in Fig 10 and 12, we see that the monocrystalline output power is higher in the low radiation region and in the low temperature region. By the same process in Figs 7 and 8, we find that the efficiency slopes for both module types tend to intersect at some point, evidently making the monocrystalline PV module more efficient at lower temperature. These observations are in agreement with reports from Abdelkader et al. (2010), Etta et al. (2015) and others.

The polycrystalline solar modules show higher efficiency because they have a lower temperature coefficient of power relative to the monocrystalline modules (Dash et al., 2015). Higher temperatures lowers the open circuit voltage (V_{oc}) but does not affect the short circuit (I_{sc}), thereby lowering the output power, with monocrystalline PV modules most affected.

6. CONCLUSION

Our findings show that in our clime, the polycrystalline PV modules exhibit higher efficiency than the monocrystalline modules. The daily average efficiency of both module types at 10% and 12% respectively certainly show good potentials for solar electricity generation in the Calabar location in Nigeria.

Considering that these investigations were carried out in the rainy season, where solar radiation as expected is relatively low as relative humidity is high, the performance index recorded should be considered adequate. The average daily solar radiation is substantially higher during the dry season in this part of Nigeria, which will further enhance the performance of PV modules in Calabar using both monocrystalline and polycrystalline PV types.

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